DIVISION 6

SECTION 3106F - GEOTECHNICAL HAZARDS AND FOUNDATIONS

3106F.1 General

3106F.1.1 Purpose. *This section provides minimum standards for analyses and evaluation of geotechnical hazards and foundations.*

3106F.1.2 Applicability. *The requirements provided herein apply to all new and existing MOTs.*

3106F.1.3 Seismic Loading. *The seismic loading for geotechnical hazard assessment and foundation analyses is provided in subsection 310F3.4.*

3106F.2 Site Characterization

3106F.2.1 Site Classes. *Each MOT shall be assigned at least one site class, based on site-specific geotechnical information. Site Classes S_A, S_B, S_C, S_D, and S_E are defined in Table 31F-6-1 and Site Class S_F is defined as follows:*

1. *Soils vulnerable to significant potential loss of stiffness, strength, and/or volume under seismic loading, such as liquefiable soils, quick and highly sensitive clays, and collapsible weakly cemented soils.*
2. *Peats and/or highly organic clays, where the thickness of peat or highly organic clay exceeds 10 feet*
3. *Very high plasticity clays with a plasticity index (PI) greater than 75, where depth of clay exceeds 25 feet.*
4. *Very thick soft/medium stiff clays, where the depth of clay exceeds 120 feet.*

3106F.2.2 Site-Specific Information.

In general, geotechnical characterization shall be based on site-specific information. This information may be obtained from existing or new sources. However, if existing or non-site specific information is used, the geotechnical engineer of record shall provide adequate justification for its use.

Site-specific investigations shall include, at a minimum, borings and/or cone penetration tests, soil classifications, configuration, foundation loading and an assessment of seismic hazards. The array (number and depths) of exploratory borings and cone penetration tests (CPT) will depend on the proposed or existing structures and site stratigraphy. The investigation or testing activities shall be completed following the procedures in Section 5 of SCEC [6.3]. CPT data may also be used by first converting to standard penetration test (SPT) data, using an appropriate method, that reflects the effects of soil gradation. If geotechnical data other than SPT and CPT are used, an adequate explanation and rationale shall be provided.

Quantitative soil information is required to a depth of 100 feet below the mudline, for assigning a Site Class

TABLE 31F-6-1

SITE CLASSES

Site Class	***Soil Profile Name/Generic Description***	***Average Values for Top 100 Feet of Soil Profile***		
		Shear Wave Velocity, V_S *[ft/sec]*	***Standard Penetration Test*** *[blows/ft]*	***Undrained Shear Strength, S_U*** *[psf]*
S_A	*Hard Rock*	*>5,000*	*-*	*-*
S_B	*Rock*	*2,500 to 5,000*	*-*	*-*
S_C	*Very Stiff/Dense Soil and Soft Rock*	*1,200 to 2,500*	*>50*	*>2,000*
S_D	*Stiff/Dense Soil Profile*	*600 to 1,200*	*15 to 50*	*1,000 to 2,000*
S_E	*Soft/Loose Soil Profile*	*<600*	*<15*	*<1,000*
S_F	*Defined in Subsection 3106F.3.1*			

Notes:
1.Site Class S_F shall require site-specific geotechnical information as discussed in subsections 3106F.2.2 and 3103F.4
2.Site Class S_E also includes any soil profile with more than 10 feet of soft clay defined as a soil with a plasticity index, PI>20, water content >40 percent and SU 500 psf.
3.The plasticity index, PI, and the moisture content shall be determined in accordance with ASTM D4318 [6.1] and ASTM D2216 [6.2], respectively.

(see Table 31F- 6-1). When data to a depth of 100 feet is unavailable, other information such as geologic considerations may be used to determine the Site Class.

3106F.3 Liquefaction. *A liquefaction assessment shall address triggering and the resulting hazards, using residual shear strengths of liquefied soils.*

3106F.3.1 Triggering Assessment. *Liquefaction triggering shall be expressed in terms of the factor of safety (SF):*

$$SF = CRR/CSR \qquad (6\text{-}1)$$

Where:

CRR = Cyclic Resistance Ratio

CSR = The Cyclic Stress Ratio induced by Design Peak Ground Acceleration (DPGA) or other postulated shaking

The CRR shall be determined from Figure 7.1 in SCEC [6.3]. If available, both the SPT and CPT data can be used.

CSR shall be evaluated using the simplified procedure in subsection 3106F.3.1.1 or site-specific response analysis procedures in subsection 3106F.3.1.2.

Shaking-induced shear strength reductions in liquefiable materials are determined as follows:

1. SF > 1.4

Reductions of shear strength for the materials for post-earthquake conditions may be neglected.

2. 1.0 < SF < 1.4

A strength value intermediate to the material's initial strength and residual undrained shear strength should be selected based on the level of residual excess pore water pressure expected to be generated by the ground shaking (e.g., Figure 10 of Seed and Harder, [6.4]).

3. $SF \leq 1.0$

Reduction of the material shear strength to a residual undrained shear strength level shall be considered, as described in subsection 3106F.3.2.

3106F.3.1.1 Simplified Procedure. *The simplified procedure to evaluate liquefaction triggering shall follow Section 7 of SCEC [6.3]. Cyclic stress ratio (CSR) is used to define seismic loading, in terms of the Design Peak Ground Acceleration (DPGA) and Design Earthquake Magnitude (DEM). DPGA and DEM are addressed in subsection 3103F.4.2. CSR is defined as:*

$$CSR = 0.65\left(\frac{DPGA}{g}\right)\left(\frac{\sigma_v}{\sigma_v'}\right)\left(\frac{r_d}{r_{MSF}}\right) \qquad (6\text{-}2)$$

where:

g = *gravitational constant*

σ_v = *the vertical total stress*

σ'_v = *the vertical effective stress*

r_d = *a stress reduction factor*

r_{MSF} = *the magnitude scaling factor*

For values of r_{MSF} and r_d, see SCEC [6.3] Figures 7.2 and 7.3, respectively. To evaluate r_{MSF}, the DEM value associated with DPGA shall be used.

3106F.3.1.2 Site Specific Response Procedure. *In lieu of the simplified procedure, either one-dimensional or two-dimensional site response analysis may be performed using the ground motion parameters discussed in subsection 3103F.4. The computed cyclic stresses at various points within the pertinent soil layers shall be expressed as values of CSR.*

3106F.3.2 Residual Strength. *The residual undrained shear strength may be estimated from Figure 7.7 of SCEC [6.3]. When necessary, a conservative extrapolation of the range should be made. Under no circumstances, shall the residual shear strength be higher than the shear strength based on effective strength parameters.*

The best estimate value should correspond to 1/3 from the lower bound of the range for a given value of equivalent clean sand SPT blowcount. When a value other than the "1/3 value" is selected for the residual shear strength, the selection shall be justified. An alternate method is provided in Stark and Mesri [6.5]. The residual strength of liquefied soils may be obtained as a function of effective confining pressures if a justification is provided. The resulting residual shear strength shall be used as the post-earthquake shear strength of liquefied soils.

3106F.4 Other Geotechnical Hazards. *For a SF less than 1.4, the potential for the following hazards shall be evaluated:*

1. *Flow slides*
2. *Slope movements*
3. *Lateral Spreading*
4. *Ground settlement and differential settlement*
5. *Other surface manifestations*

These hazards shall be evaluated, using the residual shear strength described above (subsection 3106F.3.2).

3106F.4.1 Stability of Earth Structures. *If a slope failure could affect the MOT, a stability analysis of slopes and earth retaining structures shall be performed. The analysis shall use limit equilibrium methods that satisfy all of the force and/or moment equilibrium conditions and determine the slope stability safety factor.*

1. *Slope stability safety factor $\geq$ 1.2*

   Flow slides can be precluded; however, seismically induced ground movements shall be addressed.

2. *1.0 $\leq$ Slope stability safety factor < 1.2*

   Seismically induced ground movements should be evaluated using the methods described below.

3. *Slope stability safety factor < 1.0*

   Mitigation measures shall be implemented per subsection 3106F.6.

3106F.4.2 Simplified Ground Movement Analysis. *The seismically induced ground settlement may be estimated using Section 7.6 of SCEC [6.3]. Surface manifestation of liquefaction may be evaluated using Section 7.7 of SCEC. Results shall be evaluated to determine if mitigation measures are required.*

Seismically induced deformation or displacement of slopes shall be evaluated using the Makdisi-Seed [6.6] simplified method as described below.

The stability analysis shall be used with the residual shear strengths of soils to estimate the yield acceleration coefficient, K_y, associated with the critical potential movement plane. In general, the DPGA shall be used as K_{max} (see [6.6]) and DEM as the earthquake magnitude, M. These parameters shall be used together with the upper bound curves Figures 9 – 11 of [6.6], to estimate the seismically induced ground movement along the critical plane.

However, the value of K_{max} may be different from the DPGA value to include the effects of amplification, incoherence, etc. When such adjustments are made in converting DPGA to K_{max}, a justification shall be provided. Linear interpolation using the upper bound curves in Figure 10 in [6.6] or Figure 4-10 in Ferritto et al [6.7] can be used to estimate the seismically induced ground movement for other earthquake magnitudes.

For screening purposes only, lateral spreading shall be evaluated, using the simplified equations in Youd et al. [6.8]. The total seismically induced ground displacement shall include all contributory directions.

1. *When the resulting displacement from the screening method is > 0.1 ft., the Makdisi-Seed simplified method or other similar methods shall be used to estimate lateral spreading.*

2. *If the computed displacement from the simplified method(s) is $\leq$ 0.5 ft., the effects can be neglected.*

3. *If the computed displacements using simplified methods are > 0.5 ft., the use of a detailed ground movement analysis (see subsection 6.4.3) may be considered.*

4. *If the final resulting displacement, regardless of the method used, remains > 0.5 ft., it shall be considered in the structural analysis.*

3106F.4.3 Detailed Ground Movement Analysis. *As an alternative to the simplified methods discussed above, a two-dimensional (2-D) equivalent linear or nonlinear dynamic analysis of the MOT and/or slopes and earth retaining systems may be performed.*

An equivalent linear analysis is adequate when the stiffness and/or strength of the soils involved are likely to degrade by less than one-third, during seismic excitation of less than 0.5 g's. Appropriate time histories need to be obtained to calculate seismically induced displacement (see subsection 3103F.4.2). Such analysis should account for the accumulating effects of displacement if double-integration of acceleration time histories is used. The seismic stresses or stress time histories from equivalent linear analysis may be used to estimate seismically induced deformation.

A nonlinear analysis should be used if the stiffness and/or strength of the soils involved are likely to degrade by more than one-third during seismic motion.

If the structure is included in the analysis, the ground motion directly affects the structural response. Otherwise, the uncoupled, calculated movement of the soil on the structure shall be evaluated.

3106F.5 Soil Structure Interaction

3106F.5.1 Soil Parameters. *Soil structure interaction (SSI) shall be addressed for the seismic evaluation of MOT structures. SSI may consist of linear or non-linear springs (and possibly dashpots) for various degrees of freedom, including horizontal, vertical, torsional, and rotational, as required by the structural analysis.*

Pile capacity parameters may be evaluated using the procedures in Chapter 4 of FEMA 356 [6.9]. The "p-y" curves, "t-z" curves, and tip load – displacement curves for piles (nonlinear springs for horizontal and vertical modes and nonlinear vertical springs for the pile tip, respectively) and deep foundations shall be *evaluated using Section G of API RP 2A-LRFD [6.10] including the consideration of pile group effects. Equivalent springs (and dashpots) representing the degrading properties of soils may be developed.*

Where appropriate, alternative procedures can be used to develop these parameters. Rationale for the use of alternative procedures shall be provided. One simplified method is presented in Chapter 5 of the Naval Design Manual 7.02 [6.11] and provides deflection and moment for an isolated pile, subject to a lateral load.

3106F.5.2 Shallow Foundations. *Shallow foundations shall be assumed to move with the ground. Springs and dashpots may be evaluated as per Gazetas [6.12].*

3106F.5.3 Underground Structures. *Buried flexible structures or buried portions of flexible structures including piles and pipelines shall be assumed to deform with estimated ground movement at depth.*

As the soil settles, it shall be assumed to apply shear forces to buried structures or buried portions of structures including deep foundations.

3106F.6 ***Mitigation Measures and Alternatives.*** *If the hazards and consequences addressed in subsections 3106F.3 and 3106F.4 are beyond the specified range, the following options shall be considered:*

1. *Perform a more sophisticated analysis*
2. *Modify the structure*
3. *Modify the foundation soil*

Examples of possible measures to modify foundation soils are provided in Table 4-1 of [6.7].

3106F.7 Symbols

SF = *Safety Factor*
CRR = *Cyclic Resistance Ratio*
CSR = *Cyclic Stress Ratio induced by DPGA*
g = *Gravitational constant*
σ_v = *the vertical total stress*
σ'_v = *the vertical effective stress*
r_d = *a stress reduction factor*
r_{MSF} = *the magnitude scaling factor*

3106F.8 References

[6.1] American Society for Testing and Materials (ASTM), 2002, "D4318-00 Standard Test Methods for Liquid Limit, Plastic Limit, and Plasticity Index of Soils," West Conshohocken, PA

[6.2] American Society for Testing and Materials (ASTM), 2002, "D2216-98 Standard Test Method for Laboratory Determination of Water (Moisture) Content of Soil and Rock by Mass," West Conshohocken, PA.

[6.3] Southern California Earthquake Center (SCEC), March 1999, "Recommended Procedures for Implementation of DMG Special Publication 117 Guidelines for Analyzing and Mitigating Liquefaction in California," University of Southern California, Los Angeles.

[6.4] Seed, R.B. and Harder, C.F., 1999, SPT-Based Analysis of Cyclic Port Pressure Generation and Undrained Residual Strength, Proceedings of the H.B. Seed Memorial Symposium, Editor: J.M. Duncan, BiTech Publishers Ltd., v. 2, pp. 351-376.

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[6.6] Makdisi, F.I. and Seed, H.B., "Simplified Procedure for Estimating Dam and Embankment Earthquake-Induced Deformations", ASCE Journal of the Geotechnical Engineering Division, Vol 104, No. 7, pp. 849-867.

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[6.10] American Petroleum Institute, July 1993, Recommended Practice 2A-LRFD (API RP 2A-LRFD), "Recommended Practice for Planning, Designing and Constructing Fixed Offshore Platforms – Load and Resistance Factor Design," Washington, D.C.

[6.11] "Foundations and Earth Structures", Design Manual 7.02, Chapter 5, 1986, Naval Facilities Engineering Command, Alexandria, VA.

*[6.12] Gazetas, G., "Formulas and Charts for Impedances of Surface and Embedded Foundations", Journal of Geotechnical Engineering, ASCE, Vol. 117, No. 9, September, 199*1.

Authority: Sections 8755 and 8757, Public Resources Code.

Reference: Sections 8750, 8751, 8755 and 8757, Public Resources Code.